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Handbook of Inorganic Chemicals

Pradyot Patnaik, Ph.D.

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Preface

This handbook is an encyclopedic treatment of chemical elements and their most important compounds intended for professionals and students in many areas of chemistry throughout the manufacturing, academic, and consulting communities. Chemicals are presented in alphabetical order in a descriptive format highlighting pertinent information on physical, chemical, and thermodynamic properties of chemicals, methods of preparation, industrial applications, chemical analyses, and toxic and hazardous properties. Synonyms, CAS Registry Numbers, brief history of discovery and natural occurrence are provided for many entries. The objective is to provide readers a single source for instant information about important aspects each substance. In this sense it should serve as a combination handbook and encyclopedia.

Readers may note three unique features in this text. First, there is a substantial discussion of chemical reactions of all elements and many of their compounds, a practice abandoned nowadays by most modern reference and handbooks. Second, analytical methods are presented for identification and measurement of practically all entries. In many instances, the method is based on my own research and experience. Third, a preparation method is given for all entries. For most compounds, more than one preparative method is presented, covering both laboratory and commercial production. Also, a brief history of the discovery and early production of selected elements is presented to serve as background against which modern methods may be judged and historical perspective maintained.

It has been a hard task indeed to select a limited number of compounds from among over one hundred thousand inorganic chemicals used in industry. Because of space limitations, only a small number have been selected as main entries, but many more have been cited under each entry.

I hope that you find this book useful, and that you will let the publisher and me know how we may make it more useful to you.

*Pradyot Patnaik,
Burlington, NJ.
November, 2001*

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Introduction

All of the elements and many important compounds are presented in this reference. Substances are arranged in alphabetical order. Each entry topic is discussed briefly below.

Elements

Chemical names are followed by Chemical Abstract Service (CAS) registry numbers. This is followed by symbols, atomic numbers, atomic weights, group numbers in the Periodic Table (the older but more common CAS system and the present IUPAC Group numbers given in parentheses), electron configuration, valence states, most stable oxidation states, and atomic and ionic radii. Naturally occurring stable isotopes, abundance, artificial radioactive isotopes and longest- and shortest-lived radioisotopes with half-lives are presented for all elements. Additionally for many elements, electronegativity and standard electrode potential data are presented.

The next section under “Elements” is subtitled “History, Occurrence and Uses.” This includes a brief history of chemical discoveries and the origin of their names and symbols, natural occurrence, principal minerals, abundance in the earth’s crust and in sea water and principal uses. Uses include commercial applications, preparative reactions, analytical applications and other laboratory reactions. More general information is provided in this section.

The “Physical Properties” are listed next. Under this loose term a wide range of properties, including mechanical, electrical and magnetic properties of elements are presented. Such properties include color, odor, taste, refractive index, crystal structure, allotropic forms (if any), hardness, density, melting point, boiling point, vapor pressure, critical constants (temperature, pressure and volume/density), electrical resistivity, viscosity, surface tension, Young’s modulus, shear modulus, Poisson’s ratio, magnetic susceptibility and the thermal neutron cross section data for many elements. Also, solubilities in water, acids, alkalies, and salt solutions (in certain cases) are presented in this section.

Under the title “Thermochemical Properties,” both thermodynamic and thermal properties appear. These include thermodynamic properties, enthalpies of formation, Gibbs free energy of formation, entropies and heat capacities, and

thermal properties such as thermal conductivities, coefficient of linear expansion, heat of fusion, and the heat of vaporization.

Under the "Recovery" or "Production" mining of ores, ore opening, separation, and isolation into pure elements are touched upon briefly.

The "Reactions" section highlights only important reactions that include formation of binary compounds, oxo salts, and complexes.

The "Analysis" section includes qualitative identification and quantitative measurement of the element in free elemental form or its compounds and alloys.

"Toxicity" or "Hazard" sections are presented last to illustrate dangerous properties of elements and compounds that are toxic, flammable, explosive, or otherwise harmful.

Compounds

Compounds of the elements are also presented in similar format. This includes CAS Registry Numbers, formulas, molecular weights and the hydrates they form (if any). This is followed by occurrence (for naturally occurring compounds) and industrial applications. The section on "Physical Properties" covers the color, crystal structure, density, melting and boiling points and solubilities of the compounds in water, acids, alkalies and organic solvents.

"Thermochemical Properties" mostly covers heats of formation, Gibbs free energy, entropies, and heat capacities. For many compounds, heats of fusion and vaporization are included.

Under the heading "Preparation" or "Production," preparative processes are described briefly. Chemical equations are shown wherever applicable. While "Preparation" refers to laboratory method or a general preparative method, the term "Production" refers to commercial manufacturing processes. For many compounds both historical preparative methods and those in common use are described.

The section "Analysis" starts with elemental composition of the compound. Thus the composition of any compound can be determined from its elemental analysis, particularly the metal content. For practically all metal salts, atomic absorption and emission spectrophotometric methods are favored in this text for measuring metal content. Also, some other instrumental techniques such as x-ray fluorescence, x-ray diffraction, and neutron activation analyses are suggested. Many refractory substances and also a number of salts can be characterized nondestructively by x-ray methods. Anions can be measured in aqueous solutions by ion chromatography, ion-selective electrodes, titration, and colorimetric reactions. Water of crystallization can be measured by simple gravimetry or thermogravimetric analysis.

A section on "Toxicity" is presented in many entries for poisonous and carcinogenic substances. If a substance is flammable or explosive or toxic, the section is subtitled "Hazard." Only substances that manifest poisoning effects even at small doses or are highly corrosive, or highly flammable or reactive are mentioned in this section, although most substances can be hazardous at high doses or under unusual conditions.

General and Physical Properties

Electron configuration of an atom indicates its extranuclear structure; that is, arrangement of electrons in shells and subshells. Chemical properties of elements (their valence states and reactivity) can be predicted from electron configuration.

Valence state of an atom indicates its power to combine to form compounds. It also determines chemical properties.

Electronegativity refers to tendency of an atom to pull electrons towards itself in a chemical bond. Nonmetals have high electronegativity, fluorine being the most electronegative while alkali metals possess least electronegativity. Electronegativity difference indicates polarity in the molecule.

Ionization potential is the energy required to remove a given electron from its atomic orbital. Its values are given in electron volts (eV).

Isotopes are atoms of the same elements having different mass numbers. Radioisotopes are the isotopes of an element that are radioactive or emit ionizing radiation. All elements are known to form artificial radioactive isotopes by nuclear bombardment.

Half-life of a radioactive isotope is the average time required for one-half the atoms in a sample of radioactive element to decay. It is expressed as $t_{1/2}$ and is equal to:

$$t_{1/2} = \ln 2 / \lambda, \text{ where } \lambda \text{ is a decay constant.}$$

Atomic radius refers to relative size of an atom. Among the main group of elements, atomic radii mostly decrease from left to right across rows in the Periodic Table. Going down in each group, atoms get bigger. Ionic radius is a measure of ion size in a crystal lattice for a given coordination number (CN). Metal ions are smaller than their neutral atoms, and nonmetallic anions are larger than the atoms from which they are formed. Ionic radii depend on the element, its charge, and its coordination number in the crystal lattice. Atomic and ionic radii are expressed in angstrom units of length (Å).

Standard electrode potential is an important concept in electrochemistry. Standard potentials for many half-reactions have been measured or calculated. It is designated as E° and expressed in volts (V). From the values of E° one can

predict if a species will be oxidized or reduced in solution (under acidic or basic conditions) and whether any oxidation-reduction reaction will take place.

Solubility data are presented for practically all entries. Quantitative data are also given for some compounds at different temperatures. In general, ionic substances are soluble in water and other polar solvents while the non-polar, covalent compounds are more soluble in the non-polar solvents. In sparingly soluble, slightly soluble or practically insoluble salts, degree of solubility in water and occurrence of any precipitation process may be determined from the solubility product, K_{sp} , of the salt. The smaller the K_{sp} value, the less its solubility in water.

Hardness measures ability of substances to abrade or indent one another. Several arbitrary scales have been developed to compare hardness of substances. Mohs hardness is based on a scale from 1 to 10 units in which diamond, the hardest substance, is given a value of 10 Mohs and talc given a value of 0.5.

Vapor pressure is exerted by a solid or liquid in equilibrium with its own vapor. All liquids have vapor pressures. Vapor pressure depends on temperature and is characteristic of each substance. The higher the vapor pressure at ambient temperature, the more volatile the substance. Vapor pressure of water at 20°C is 17.535 torr.

Refractive index or index of refraction is the ratio of wavelength or phase velocity of an electromagnetic wave in a vacuum to that in the substance. It measures the amount of refraction a ray of light undergoes as it passes through a refraction interface. Refractive index is a useful physical property to identify a pure compound.

Temperature at the critical point (end of the vapor pressure curve in phase diagram) is termed critical temperature. At temperatures above critical temperature, a substance cannot be liquefied, no matter how great the pressure. Pressure at the critical point is called critical pressure. It is the minimum pressure required to condense gas to liquid at the critical temperature. A substance is still a fluid above the critical point, neither a gas nor a liquid, and is referred to as a supercritical fluid. The critical temperature and pressure are expressed in this text in °C and atm, respectively.

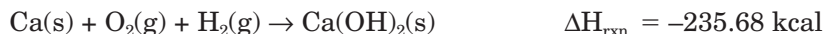
Viscosity is a property of a fluid indicating its resistance to change of form (or resistance to flow). It is expressed as g/cm sec or Poise; 1 Poise = 100 centipoise.

Surface tension occurs when two fluids are in contact with each other. This is caused by molecular attractions between the molecules of two liquids at the surface of separation. It is expressed as dynes/cm or ergs/cm².

Modulus of elasticity is the stress required to produce unit strain to cause a change of length (Young's modulus), or a twist or shear (shear modulus), or a change of volume (bulk modulus). It is expressed as dynes/cm².

Thermochemical and Thermal Properties

The enthalpy of formation, ΔH_f° , is the energy change or the heat of reaction in which a compound is formed from its elements. Two examples are shown below:





The ΔH_f° in the above reactions are -235.68 and -11.02 kcal/mol, respectively. In the second case, the value of ΔH_f° is one-half of ΔH_{rxn} since two moles of NH_3 are produced in the reaction. Also note that ΔH_f° refers to the formation of a compound from its elements only at the standard state (25°C and 1 atm), and not the formation from other compound(s).

The term ΔG_f° refers to the standard free energies of formation of compounds at 25°C and 1 atm . Its relation with enthalpy change, ΔH , and entropy change, ΔS , at a temperature T (in $^\circ\text{K}$) can be expressed as:

$$\Delta G = \Delta H - T\Delta S$$

The value of ΔG_f° can be calculated from the above equation and from other equations also.

Entropy is a thermodynamic quantity that is a measure of disorder or randomness in a system. When a crystalline structure breaks down and a less ordered liquid structure results, entropy increases. For example, the entropy (disorder) increases when ice melts to water. The total entropy of a system and its surroundings always increases for a spontaneous process. The standard entropies, S° are entropy values for the standard states of substances.

Heat capacity, C_p is defined as the quantity of thermal energy needed to raise the temperature of an object by 1°C . Thus, the heat capacity is the product of mass of the object and its specific heat:

$$C_p = \text{mass} \times \text{specific heat}$$

Specific heat is the amount of heat required to raise the temperature of one gram of a substance by 1°C . The specific heat of water is 1 calorie or 4.184 Joule.

The heat of fusion, ΔH_{fus} is the amount of thermal energy required to melt one mole of the substance at the melting point. It is also termed as latent heat of fusion and expressed in kcal/mol or kJ/mol.

The heat of vaporization, ΔH_{vap} , is the amount of thermal energy needed to convert one mole of a substance to vapor at boiling point. It is also known as latent heat of vaporization and expressed kcal/mol or kJ/mol.

Thermal conductivity measures the rate of transfer of heat by conduction through unit thickness, across unit area for unit difference of temperature. It is measured as calories per second per square centimeter for a thickness of one centimeter and a temperature difference of 1°C . Its units are $\text{cal/cm sec.}^\circ\text{K}$ or $\text{W/cm}^\circ\text{K}$.

The coefficient of linear thermal expansion is the ratio of the change in length per degree C to the length at 0°C .

Analysis

All metals at trace concentration, or in trace quantities, can be analyzed by atomic absorption (AA) spectrophotometry in flame or graphite furnace (electrothermal reduction) mode. A rapid, multi-element analysis may use

advanced instruments available commercially. Also, Inductively Coupled Plasma Atomic Emission Spectrophotometric methods (ICP-AES) are rapid, versatile, and multi-element analytical methods. They offer certain advantages over flame or furnace AA. ICP/MS (mass spectrometry) is the most sensitive technique because it provides a detection level over one hundred times lower than AA or ICP. For all such analyses, solid compounds must be dissolved in water by acid digestion or alkali fusion. Other instrumental techniques for metal analyses include x-ray fluorescence, x-ray diffraction, neutron activation analysis, and ion-specific electrode methods. Also, colorimetric methods that are prone to interference effects may be applied to identify metals in their pure salts.

Anions may be measured best by ion chromatography, using appropriate anion exchange resin columns that are available commercially. Salts may be diluted for such measurements. Ion-selective electrode methods also yield satisfactory results at trace concentrations. Numerous colorimetric methods are reported in literature. They are susceptible to erroneous results when impurities are present. Many titration methods are available in analytical chemistry. They may be applied successfully to measure certain anions, oxidizing and reducing substances, acids, and bases.

Thermogravimetric analysis (TGA) and the differential thermal analysis (DTA) may be used to measure the water of crystallization of a salt and the thermal decomposition of hydrates.

Substances also can be identified from physical properties such as density, melting and boiling points, and refractive index. Elemental analysis can confirm the identity of a compound.

Hazard

Toxicity of many entries are expressed quantitatively as LD₅₀ (median lethal dose) or LC₅₀ (median lethal concentration in air). The latter refers to inhalation toxicity of gaseous substances in air. Both these terms refer to the calculated concentration of a chemical that can kill 50% of test animals when administered.

A substance is usually termed “flammable” if its flash point is below 100°F (38°C).

Some Physical Constants

Velocity of light, $c = 2.9979 \times 10^8$ m/s (in vacuum)

Planck's constant, $h = 1.05457 \times 10^{-34}$ J.s

Rydberg constant, $R_H = 2.17991 \times 10^{-18}$ J

Boltzmann constant, $k = 1.3807 \times 10^{-16}$ erg/K

Acceleration of gravity, $g = 980.6$ cm/s

Electron mass, $m_e = 9.1094 \times 10^{-31}$ kg

Proton mass, $m_p = 1.6726 \times 10^{-27}$ kg

Neutron mass, $m_n = 1.6749 \times 10^{-27}$ kg

Proton-electron mass ratio = 1836

Atomic mass unit (amu) = 1.6605×10^{-27} kg

Electron charge, $e = 1.60219 \times 10^{-19}$ C

Faraday constant, $F = 9.648456 \times 10^4$ C

Avogadro constant = 6.022×10^{23} /mol

Molar volume at STP = 22.41384 L

Molar gas constant, $R = 0.08026$ L. atm/mol. K

$= 8.3145$ J/mol. K

$= 1.9872$ cal/mol. K

Units and Conversion

Temperature

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$$

$$^{\circ}\text{F} = 1.8^{\circ}\text{C} + 32$$

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273.15$$

Pressure

$$\begin{aligned} 1 \text{ atm} &= 101.365 \text{ KPa} \\ &= 101,365 \text{ Pa} \\ &= 0.101365 \text{ MPa} \end{aligned}$$

$$1 \text{ MPa} = 9.87 \text{ atm}$$

$$1 \text{ atm} = 760 \text{ torr} = 760 \text{ mm Hg}$$

$$1 \text{ atm} = 14.696 \text{ psi}$$

$$1 \text{ KPa} = 7.50 \text{ torr}$$

Volume

$$1 \text{ L} = 1,000 \text{ mL}$$

$$1 \text{ mL} = 1 \text{ cubic centimeter (cc)}$$

$$1 \text{ m}^3 = 1000 \text{ L}$$

$$1 \text{ gal (US)} = 3.784 \text{ L}$$

$$1 \text{ quart (qt)} = 946.4 \text{ mL}$$

$$1 \text{ tablespoon} = 14.79 \text{ mL}$$

$$1 \text{ teaspoon} = 4.93 \text{ mL}$$

Energy

$$1 \text{ cal} = 4.184 \text{ J}$$

$$1 \text{ kcal} = 1,000 \text{ cal}$$

$$1 \text{ kJ} = 1,000 \text{ J}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

$$1 \text{ MeV} = 1.602 \times 10^{-13} \text{ J}$$

Distance, Bond Length and Atomic Radii

$1 \text{ km} = 1,000 \text{ m}$
 $1 \text{ m} = 100 \text{ cm or } 1,000 \text{ mm}$
 $1 \text{ mm} = 1,000 \text{ }\mu\text{m}$
 $1 \text{ }\mu\text{m} = 1,000 \text{ nm}$
 $1 \text{ nm} = 1,000 \text{ pm}$
 $1 \text{ m} = 10^6 \text{ }\mu\text{m or } 10^9 \text{ nm}$
 $1 \text{ mho} = 1 \text{ siemen (S)}$
 $1 \text{ }\text{\AA} = 10^{-10} \text{ m}$
 $1 \text{ }\text{\AA} = 10 \text{ pm}$
 $1 \text{ micron} = 1 \text{ micrometer (}\mu\text{m)}$

Density

$\text{Solid} = \text{g/cm}^3$
 $\text{Liquid} = \text{g/mL}$
 $\text{Gas} = \text{g/L}$
 $\text{Density of gas/vapor at STP} = \text{molecular wt(g)}/22.4 \text{ L}$
 $\text{Vapor density (times heavier than air)} = \text{molecular wt}/29$

Concentration

$1 \text{ ppm (w/w)} = 1 \text{ mg/L (in aqueous solution)}$
 $1 \text{ M} = \text{mol/L}$
 $1 \text{ N} = \text{gram equivalent weight/L}$
 $1 \text{ m} = \text{mol/kg solvent}$

Miscellaneous

$1 \text{ dyne/cm}^2 = 0.10 \text{ Pa}$
 $1 \text{ erg} = 10^{-7} \text{ J}$
 $1 \text{ erg/s} = 10^{-7} \text{ watt (W)}$
 $1 \text{ Faraday} = 96,495 \text{ coulomb (C)}$
 $1 \text{ inch} = 2.54 \text{ cm}$
 $1 \text{ mho} = 1 \text{ siemen (S)}$
 $1 \text{ ohm.cm} = 10^{-2} \text{ ohm.m}$
 $1 \text{ ohm.cm} = 10^6 \text{ microhm.cm}$
 $1 \text{ centipoise} = 0.001 \text{ Pascal-second}$
 $1 \text{ centistoke} = 1 \times 10^{-6} \text{ m}^2/\text{sec}$

Bibliography

Some general bibliographic references follow. Additional references from journals and historical literature have been cited in the text.

1. *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd ed., Vol 1-23, 1970-86; New York: John Wiley & Sons
2. *The Encyclopedia of Chemical Elements*, ed. Clifford A. Hempel, 1968, New York: Reinhold Book Corporation
3. *CRC Handbook of Chemistry and Physics*, 77th ed., edited. David R. Lide, 1999, Boca Raton: CRC Press
4. Cotton, F.A., Wilkinson, G., Murillo, C.A. and M. Bochmann. 1999. *Advanced Inorganic Chemistry*, 6th ed., New York: John Wiley & Sons
5. Patnaik, P. 1999. *A Comprehensive Guide to the Hazardous Properties of Chemical Substances*, 2nd ed. New York: John Wiley & Sons
6. Lewis(Sr.), R.J. 1996 *Sax's Dangerous Properties of Industrial Materials*, 9th ed. New York: Van Nostrand Reinhold
7. *The Merck Index*, 12thed, edited. Susan Budavery, 1995 Rahway, NJ: The Merck and Company, Inc.
8. American Public Health Association, American Water Works Association and Water Environment Federation. 1999. *Standard Methods for the Examination of Water and Wastewater*, 20th ed. Edited Arnold E. Greenberg, Lenore S. Clesceri, and Andrew D. Easton. Washington, DC: American Public Health Association.
9. *The Merck Index*, 12th ed, edited. Susan Budavery, 1995 Rahway, NJ: The Merck and Company, Inc.
10. American Public Health Association, American Water Works Association and Water Environment Federation. 1999. *Standard Methods for the Examination of Water and Wastewater*, 20th ed. Edited Arnold E. Greenberg, Lenore S. Clesceri and Andrew D. Easton. Washington, DC: American Public Health Association
11. Patnaik, P. 1997. *Handbook of Environmental Analysis*, Boca Raton: CRC Press
12. Skoog, D.A. West, D.M. and F. James Holler. 1992. *Fundamentals of Analytical Chemistry*, 6th ed. 1992. New York: Saunders College Publishing
13. Silberberg, M. 1996. *Chemistry, The Molecular Nature of Matter and Change*, St. Louis: Mosby
14. H. Remy. 1956. *Treatise on Theoretical and Inorganic Chemistry*, Amsterdam: Elsevier Publishing Company

ABBREVIATIONS AND STANDARD LETTER SYMBOLS

Absorbance (decadic)	<i>A</i>	Chemical shift	δ
Absorption coefficient, linear decadic	<i>a</i>	Citrate	Cit
Activation energy	<i>E_a</i>	Compare (confer)	cf.
Activity (radioactive)	<i>A</i>	Concentration at peak maximum	<i>C_{max}</i>
Adjusted retention time	<i>t'_R</i>	Concentration of solute in mobile phase	<i>C_M</i>
Adjusted retention volume	<i>V'_R</i>	Concentration of solute in stationary phase	<i>C_s</i>
Alcohol	alc	Conductance	<i>G</i>
Alkaline	alk	Conductivity	κ
Alpha particle	α	Coulomb	<i>C</i>
Alternating current	ac	Critical temperature	<i>t_c</i>
Amorphous	am	Cross section	σ
Amount concentration	<i>c</i>	Curie	Ci
Amount of substance	<i>n</i>	Cycles per second	Hz
Ampere	<i>A</i>	Dalton (atomic mass unit)	Da
Angle of optical rotation	α	Decay constant (radioactive)	λ
Angstrom	$\text{\AA}$	Decompose	dec
Angular dispersion	<i>dθ/dλ</i>	Degree of dissociation	α
Angular velocity	ω	Degrees Celsius	°C
Anhydrous	anhyd	Density, critical	<i>d_c</i>
Approximate	ca.	Detect, determine(d)	det(d)
Aqueous solution phase	aq	Diffusion coefficient	<i>D</i>
Area	<i>A</i>	Diffusion coefficient, mobile phase	<i>D_M</i>
Atmosphere, unit of pressure	atm	Diffusion coefficient, stationary phase	<i>D_s</i>
Atomic mass unit	amu	Diffusion current	<i>i_d</i>
Atomic percent	at. %	Dilute	dil
Atomic weight	at. wt.	Direct current	dc
Average	av	Disintegration per minute	dpm
Average linear gas velocity	μ	Distribution ratio	<i>D</i>
Band width	σ^2	Dropping mercury electrode	dme
Bar, unit of pressure	bar	Electric current	<i>I</i>
Barn, cross section (radioactivity)	b	Electric potential	<i>V</i>
Base of natural logarithms	<i>e</i>	Electrical resistance	<i>R</i>
Becquerel	Bq	Electromotive force	<i>E</i> , emf
Bed volume	<i>V_g</i>	Electron	<i>e⁻</i> , <i>e</i>
Beta particle	β	Electronvolt	eV
Bohr magneton	μ_B	Equivalent weight	equiv wt,
Boiling point	bp		eq wt
Boltzmann constant	<i>k_B</i>	et alii (and others)	et al.
Bragg angle	θ	et cetera (and so forth)	etc.
Butyl	Bu	Ethyl	Et
Calorie, unit of energy	cal	Ethylenediamine- <i>N,N,N',N'</i> -tetra-	EDTA
Capacitance	<i>C</i>	acetic acid	
Celsius temperature	<i>t</i>		
Charge number of an ion	<i>z</i>		

ABBREVIATIONS AND STANDARD LETTER SYMBOLS (Continued)

Exempli gratia	e.g.	Oxidant	ox
Exponential	exp	Page(s)	p. (pp.)
Faraday constant	F	Partition ratio	k'
Flowrate, column chromatography	F_c	Parts per billion, volume	ng/mL
Freezing point	fp	Parts per billion, weight	ng/g
Gamma radiation	γ	Parts per million, volume	$\mu\text{g/mL}$
Gas (physical state)	g	Parts per million, weight	$\mu\text{g/g}$
Gas constant	R	Pascal	Pa
Gauss	G	Peak resolution	R_s
Gram	g	pH, expressed in activity	paH
Half-life	$t_{1/2}$	expressed in molarity	pH
Half-wave potential	$E_{1/2}$	Phenyl	Ph
Hertz	Hz	Plate number, effective	N_{eff}
Hour	h	Pounds per square inch	psi
Hygroscopic	hygr	Pressure, critical	p_c
ibidem (in the same place)	ibid.	Propyl	Pr
id est (that is)	i.e.	Pyridine	py
Inch	in	Radiofrequency	rf
Inorganic	inorg	Reductant	red
Inside diameter	i.d.	Retardation factor	R_f
Insoluble	insol	Retention time	t_R
In the same place	ibid.	Retention volume	V_R
In the work cited	op. cit.	Saturated	satd
Joule	J	Saturated calomel electrode	SCE
Kelvin	K	Second	s
Kilo-	k-	Signal-to-noise ratio	S/N
Liter	L	Slightly	sl
Logarithm, common	log	Solid	c, s
Logarithm, base e	ln	Soluble	sol
Mass absorption coefficient	$\mu/\rho, \mu_m$	Solution	soln
Maximum	max	Solvent	solv
Melting point	mp	Standard	std
Meter	m	Tartrate	tart
Milliequivalent	meq	Transit time of nonretained solute	t_M, t_0
Millimeters of mercury, pressure unit	mmHg	Ultraviolet	uv
Millimole	mM	Vacuum	vac
Minute	m, min	Velocity	u, w
Molar	M	Versus	vs
Mole	mol	Volt	V
Mole percent	mol %	Volume	V, v
Molecular weight	mol wt	Volume mobile phase in volume	V_M
Neutron	n	Volume per volume	v/v
Nuclear magnetic resonance	NMR	Weight	W
Ohm	Ω	Weight percent	wt %
Organic	org	Weight per volume	w/v
Outer diameter	o.d.	Zone width at base	W_b
Oxalate	Ox	Zone width at one-half peak height	$W_{1/2}$

About the Author

Pradyot Patnaik, Ph.D., is Director of the Laboratory of the Interstate Environmental Commission at Staten Island, NY. He also teaches as an Adjunct Professor at the New Jersey Institute of Technology in Newark, NJ, and Community College of Philadelphia and does his research in the Center for Environmental Science at the City University of New York on Staten Island. His diverse interests include chemical processing, product development, catalysis, reaction mechanisms, environmental pollutants, and mass spectrometry.

Dr. Patnaik was a post-doctoral research scientist at Cornell University, Ithaca, NY. His B.S. and M.S. in chemistry are from Utkal University, India, and his Ph.D. from the Indian Institute of Technology, Bombay.

Dr. Patnaik has written two other books, *A Comprehensive Guide to the Hazardous Properties of Chemical Substances*, and *Handbook of Environmental Analysis*.